Office of Naval Research International Field Office

24. High Temperature Superconductors (HTSC)

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Key Words: *Coated conductors, Textured substrate (TS) tape wires, Aligned buffer layer (ABL) wires, Rapid growth superconducting layer (RGSL) wires, Bi-system HTSC, Magnetic separation, water purification*

1. Summary

Coated Conductors

A project on high temperature superconductor (HTSC) wires is under way in the form of a consortium between the Superconductivity Research Laboratory/International Superconductivity Technology Center (SRL/ISTEC) and several industries (Tokyo & Chubu Electric Power Co., Showa Electric Wire & Cable Co., Toshiba Corporation, Fujikura Ltd., and Furukawa & Sumitomo Electric Co). The project receives financial support from the New Energy and Industrial Technology Development Organization (NEDO). The ultimate goal is to produce HTSC tape wires with the critical current density (J_c) = $10^5 - 10^6$ A/cm^2 at 77 K and a length of 10−1000 m at the production rate > 10 m/h. The R & D organization is summarized in Fig. 1.

$REBa_2Cu_3O_x$ (RE123: rare earth metals (RE) like Y, Nb, Sm etc.), which can transmit high currents at liquid nitrogen temperature (77 K) under high magnetic fields (1-5 Tesla: T), are used as HTSC materials. Since the formability of RE123 is very poor and the J_c is substantially affected by the misorientation at grain boundaries, coated conductors, first designed in the USA, are considered as next generation HTSC wires. The coated conductors consist of several components;

- Substrate (Ni-based alloys, Ni, Ag or clad type alloys: 50-150 μm thick)
- Buffer layer (Y_2O_3 stabilized ZrO_2 (YSZ), MgO, CeO_2, NiO, $BaZrO_2$: < 3 μm thick)
- Superconducting layer ($REBa_2Cu_3O_x$: 0.5-10 μm thick)
- Stabilizing layer (Ag, Ag/Cu: 3-10 μm thick)

In the coated conductors, textured substrates or buffer layers allow quasi-single crystalline superconducting layers to grow. There are three types of coated conductors being developed in this program.

Textured Substrate (TS) Wires

Ni- or Ag-based substrates have been textured by rolling and recrystallization treatment. Buffer layers of NiO 50 m long were deposited over textured Ni substrates using a surface oxidation epitaxy (SOE) method. Such SOE-NiO/Ni had in-plane texture similar to textured Ni. Y123 (the critical temperature: T_c = 93 K) deposited over MgO/SOE-NiO/Ni showed J_c = 3 x 10^5 A/cm^2 (77 K & 0 T). To increase the wire strength and suppress the magnetization of coated conductors, clad-type composites of Ni/Ni-Cr and Ni/stainless steel were used as the substrate. A pulsed laser deposition (PLD) technique enabled the deposition of Y123 over Ag-Cu/Ag-Ni/Ag-Cu clad-type composites, resulting in a strength increase of a factor of 4 over that of Ag. Ag clad-type composite wires indicated constant values of J_c = 1.2 x10^5 A/cm^2 (77 K & 0 T) along the length of 1 m.

Aligned Buffer Layer (ABL) Wires

ABL tape wires, in which textured substrates are not needed, are a Japanese unique technology. During ABL wire processing, epitaxial growth of a superconducting layer can be achieved on three-dimensionally textured buffer layers. Japanese research groups succeeded in fabricating textured YSZ buffer layers using an ion beam assisted deposition (IBAD) method, which produces better crystalline textures and smooth surfaces, or an inclined substrate deposition (ISD) method with fast growth rates. The use of a large-scale IBAD system with a rectangle ion source made it possible for buffer layers, made up of textured $Zr_2Gd_2O_7$, to grow at the rate of 1 m/h. ABL wires 10 m long had J_c > 10^5 A/cm^2. By applying an ISD system operated by a new exima laser source with long-term stability, ABL wires were manufactured with similar length and J_c to those made by the IBAD. The Japanese project ultimately targets to fabricate ABL wires with length of more than 50 m using the advanced IBAD and ISD methods.

Rapid Growth Superconducting Layer (RGSL) Wires

The TS and ABL tape wires have thinner conductive layers relative to the substrate thickness. Because these wires arise from slow crystal growth, there is the inherent degradation problem of thick films, leading to reduction in the effective J_c of TS and ABL wires through the thickness. In order to overcome the drawback, trifluoroacetate-metal organic deposition (TFA-MOD) and liquid phase epitaxy (LPE) methods are being applied to cause HTSC films to grow rapidly. By using the TFA-MOD method, the deposition of Y123 was made over CeO_2/IBDA-YSZ/Hastelloy. The RGSL wire showed $J_c = 2.5 \times 10^6$ A/cm^2 (77 K & 0 T) and $J_c > 10^5$ A/cm^2 (77 K & $B_{\perp}$= 2 T, $B_{//}$ =5 T). The LPE method is crystal growth processing under near-equilibrium state, which does not require a vacuum chamber and can achieve thick films. Superconducting layers were successively applied over ISD-MgO/Hastelloy and SOE-NiO/textured Ni by controlling the chemical reaction between the metal and solution during the LPE processing.

Bi-system HTSC at National Institute for Materials Science (NIMS)

Since a NIMS scientist first invented Bi-system HTSC in 1988, Bi2212 ($Bi_2Sr_2Ca_1Cu_2O_x$) wires have been extensively studied at the NISM. The project is ongoing in collaboration with Hitachi Ltd. and Hitachi Electric Cable Co. Although the J_c of Bi2212 with T_c = 80-90 K is easily reduced at 77 K under strong magnetic fields, the construction of Bi-system HTSC wires requires a simpler structure than coated conductors. Ag-coated Bi2212 wires, with c-axis texture parallel to the tape plane, can be made by a powder-in-tube or dip-coating method. Recently, rotation-symmetric arranged tape-in-tube (ROSAT) Bi2212/Ag or Ag-Mg-Ni/Ag wires have been made, which have the diameter of 1.78 mm and length of 2-3 km. Round and rectangular ROSAT wires, consisting of more than 1000 filaments (Bi2212) with 9-12 μm thick, depicted $J_c \cong 1.5 \times 10^3$ A/cm^2 at 4.2 K & 24 T and the yield strength of 44-80 MPa.

Application of Bulk HTSC for Magnetic Separation

A new magnetic separation system for continuous water purification has been developed by the SRL & Hitachi Ltd. In this system, the use of bulk HTSC ($YBa_2Cu_3O_7$) can rapidly remove contaminants like organic matter and plankton, e.g. blue-green algae, from water supplies. The schematic drawing of the system is shown in Fig. 2. Its new membrane-magnetic separator consists of three components:

(i) Preapplication treatment unit in which magnetic flocs made of suspended solids and seeded with ferromagnetic particles (Fe_2O_3) are coagulated in a flocculation vessels
(ii) Membrane separator that purifies water by using a rotating net to gather the flocs
(iii) Magnetic separators that recovers the magnetic flocs on the net

The maximum magnetic field of the bulk HTSC at 34 K is 3.2 T. This system simultaneously removed 98% of the contaminants and recovered sludge at a concentration of 40,000 mg/l.

Magnesium Boride (MgB_2)

Prof. Akimitsu' group at Aoyama Gakuin University has developed a new class of superconducting intermetallic compound (MgB_2). High purity MgB_2 was prepared by the following process: Pellets were first formed by pressing mixed Mg and B powers with1: 2 ratio. Ta foil-wrapped pellets were inserted into a graphite crucible and then HIPed under 196 MPa at 973-1173 K for 1- 10 h in Ar atmosphere. MgB_2 with hexagonal structure has the T_c of 39 K, which is the highest among metallic superconductors, and shows superconductivity at 25 K under 10 T. The J_c of bulk MgB_2 was 10^6 A/cm^2 at 0 T and 10^2 A/cm^2 at 10 T, which is 10-100 times smaller than that of bulk Nb_3Sn and Nb-Ti. Indium (In)-doped MgB_2 prepared by Prof. Tachikawa at Tokai University can be drawn at lower temperatures of 473 K than at 1223 K for MgB_2. The wire of In-doped MgB_2 had 10^6 A/cm^2, which is five times higher than those of MgB_2 wires.

2. Background

While significant coated conductors research efforts are underway in Japan, it appears that the prospect for using such HTSC tape wires as long cables is in doubt due to high production costs. Bi-system HTSC, such as ROSAT wires, would be a little more attractive despite magnetic fields limiting the application and the required use of precious metals such as Ag.

3. Assessment

ABL tape wires were produced using advanced IBAD and ISD methods in Japan. Magnetic separators developed by applying bulk HTSC would draw Navy interests.

4. Points of Contact

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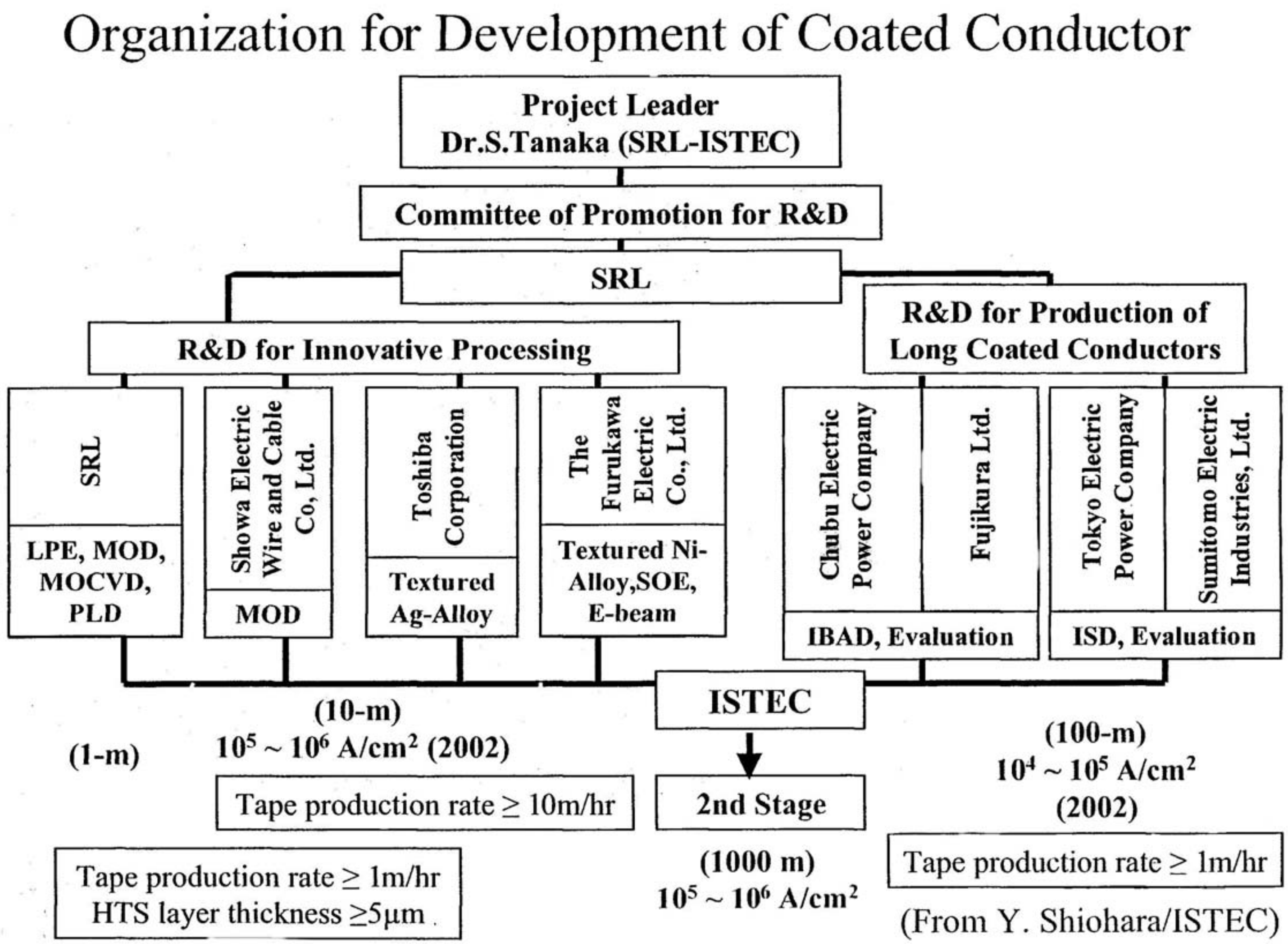

Figure 1. R & D organization of Coated Conductors

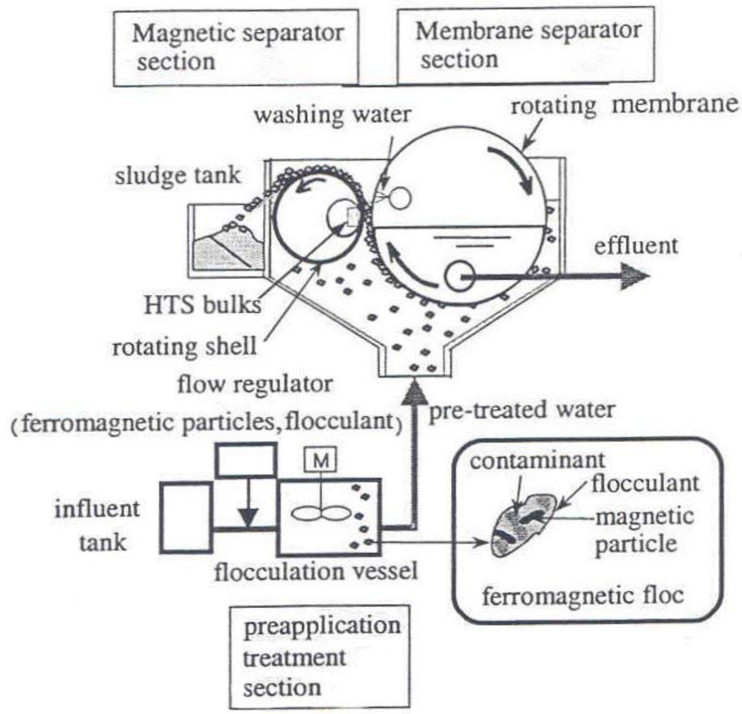

Figure 2. Structure of high-T_c bulk superconductor-based membrane magnetic separator for water purification